The Gossamer Initiative

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Abstract

The Gossamer Spacecraft Initiative is a new NASA program to begin long-range development of enabling technologies for very large, ultra-lightweight structures and apertures. Large apertures include optical, infrared and sub-millimeter telescopes, "photon buckets" for optical communications and "non-coherent" imaging, solar concentrators, and radio frequency antennas. Developments in the very large ultra-light structures will be focused on one of their most challenging applications - solar sails. The sail structures will include both 3-axis stabilized and spinning. Gossamer spacecraft technology will eventually allow NASA to undertake bold new missions of discovery, such as searching for the signs of life on planets orbiting nearby stars, and sailing through space on beams of light to places beyond our solar system.

Program Vision

"Technology to find it and then shake its hand" is a long-term vision of the Gossamer Spacecraft Initiative. This somewhat humorous sounding motto appears even more outrageous when translated into scientific terms. NASA will develop technology to enable imaging of extra-solar planets to detect the ones, which carry life. Once we find such planets we will not be satisfied with "just" creating somewhat blurred pictures of these worlds or having spectroscopic "smoking guns" of life existence - we will want to travel there and take a closer look at our cosmic friends. We do not know how long this search will take; we do not know how successful we will be. One thing we do know, is that to make this vision more than just science fiction we will need to develop radically different observatories and spacecraft.

A Gossamer telescope that which will produce the first detailed image of an extrasolar planet will bear little resemblance to any current space observatories.

The Gossamer telescope will be about 100 times lighter than the Hubble Space Telescope and its diameter will be 10-20 times greater. When such a telescope, or an interferometer consisting of an array of such telescopes, will finally produce an image of "the other world," there will be strong public summon to take even a closer look.

In this day and age we envision three major ways that offer the possibility of interstellar travel. They are: matter-antimatter propulsion, nuclear propulsion and solar sailing. The propulsion method that recently has been getting the most attention is solar sailing. The first generation interstellar sail missions are envisioned to use gravitational boost from the sun in addition to the solar pressure. In the more distant future the sails will be propelled by lasers.

The Gossamer Initiative will develop technology that will eventually make an interstellar sailing possible.

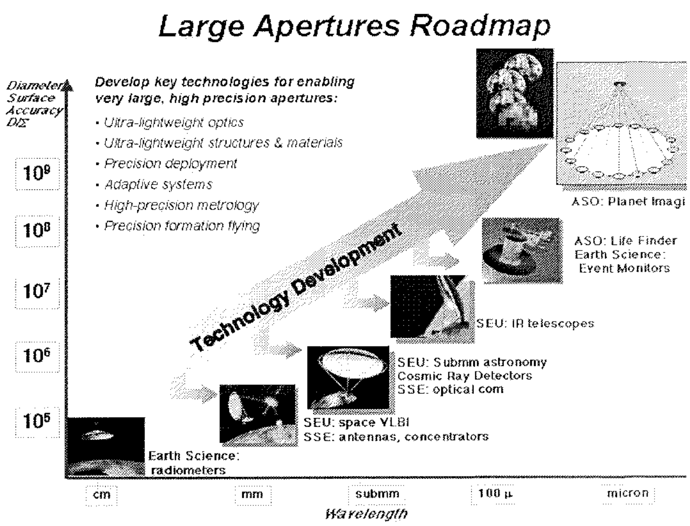

Figure 1. Gossamer apertures technology development roadmap

The "vision missions" of the Initiative are the Interstellar Probe and the Extrasolar Planet Imager.

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Both of these missions can be considered the pinnacles of the technology development roadmap. Before the technology is ready to enable either of these vision missions, there will be a series of technology development products benefiting several types of space endeavors as shown on figures 1 and 2. Figure 1 shows a number of candidate missions that will be enabled on the way to developing 20-40 meter diameter class optical apertures needed for a planet imager.

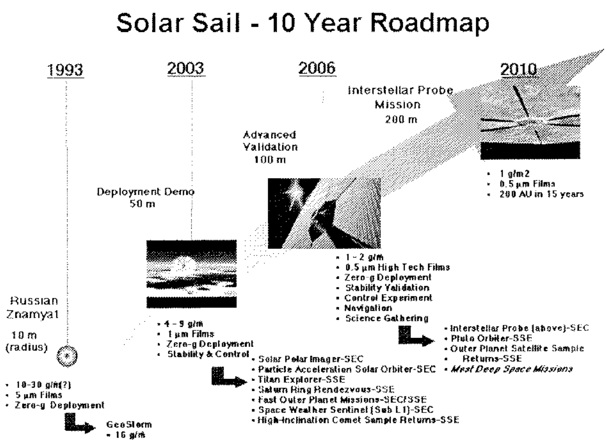

Figure 2 Gossamer sail technology development roadmap

Likewise, Figure 2, shows what solar sail missions will benefit from progress in Gossamer technology development.

Program Background

Gossamer spacecraft technology will enable very large, ultra-lightweight systems for bold missions of discovery such as:

- Very large telescopes for imaging extra-solar planets, studying formation of large-scale structure in the early universe, and continuously monitoring the Earth from distant vantage points.
- Large deployable and inflatable antennas for space-based radio astronomy, high-bandwidth communications from deep space, and Earth remote sensing with radar and radiometers.
- Solar sails for low-cost propulsion, station keeping in unstable orbits, and precursor interstellar exploration missions.
- Large solar power collection and transmission systems for human and robotic exploration missions, and for the commercial development of space.

The overarching goal of gossamer spacecraft technology development is to achieve breakthroughs in mission capability and cost, primarily through revolutionary advances in structures, materials, optics, and adaptive and multifunctional systems.

NASA is studying future missions requiring very large space observatories. The long-range goal of the Astronomical Search for Origins and Planetary Systems (ASO) theme in the Space Science Enterprise is to detect and characterize planets in orbit around nearby stars. This grand challenge is a driver of gossamer technology development for large apertures.

Independent of any specific instrument concept, the basic detection physics sets minimum requirements for the optical apertures.Set against the benchmark of the largest ground-based telescopes and the 8-meter Next Generation Space Telescope (NGST), terrestrial planet spectroscopic characterization requires a ten-fold increase in aperture area, and low-resolution direct imaging requires an additional 25-fold increase in area. Such large collection area requirements most likely preclude implementing the missions with single telescopes. Rather, such missions are currently envisioned to utilize constellations of large telescopes flying in formation and operating as interferometers.

The basic building block for these systems is likely to be diffraction-limited optical collectors of 20-40 meter diameter. One of the critical metrics for such systems is the areal density of the fully loaded primary mirror (optical surface, reaction structure, actuators, and wiring). An aerial density of 100 kg/m^2 is typical for conventional telescopes, and the Next Generation Space Telescope (NGST) is striving to achieve aerial densities between 10 and 15 kg/m^2. For future ASO missions, areal densities of 1 kg/m^2 or less are required to enable affordable system architectures. Ultimately, to achieve higher resolution imagery and spectroscopy, even more aggressive architectures with collecting areas equivalent to much larger (100's – 1000's of meters) aperture diameters and much lower areal densities ($< 0.1 kg/m^2$) will be required.

Large aperture technologies also have direct applicability to the needs of other NASA missions. For example, the Structure and Evolution of the Universe (SEU) theme needs large apertures for advanced X-ray, space radio frequency, microwave, and submillimeter telescopes. Large space radio telescopes and Earth observing antennas such as for soil moisture and ocean salinity measurements will need great improvements in antenna technology in the near term. These new antennas will be characterized by: sizes exceeding 25 meters in diameter, fraction of a kilogram per square meter density and operating frequencies between 1-100 GHz.

Other applications that could benefit from large aperture technology include high-resolution imagers for land and tropospheric wind studies, radar for Earth and Space Science, deep-space communications, and large-scale solar power generation.

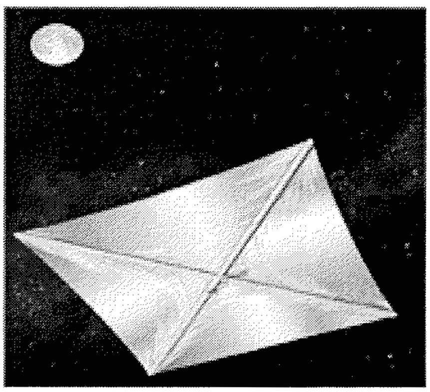

Figure 3 Sail Occulter concept by Glenn Starkman, Case Western Reserve University

Solar sails are being considered for several missions planned in the Sun-Earth Connection (SEC) theme, including a Solar Polar Imager, and a first generation Interstellar Probe launched to explore the outer reaches of the solar system. Several missions of the Solar System Exploration (SSE) theme would also be greatly enhanced by the use of solar sails, such as missions to comets and the outer planets. This technology could also enable large sunshields needed to stabilize and protect large gossamer apertures and other cryogenic telescopes.

Program Metrics

Hubble Space Telescope (HST) represents the current state of the art in space apertures. The aperture size of the HST is 2.4 meters diameter and the areal density of the aperture system is approximately 150 kg/m^2. The Gossamer Initiative will advance these parameters to 20-40 meter for aperture diameters and less than 1 kg/m^2 densities. In the area of solar sails it is difficult to specify what the state of the art is as no solar sail has ever flown. The cost of these systems will also have to be drastically reduced. No firm metrics for cost exist yet, but it is expected that the current level of funding per mission will not increase in the future. Even the most capable telescopes will have to stay within a cost cap of the currently planned telescopes such as NGST or Terrestrial Planet Finder (TPF). To quote Dr. Roger Angel and Dr. Neville Woolfe from their 1996 Scientific American article "we would need an enormous space telescope, close to 60 meters in diameter. With current [1996] technology, the cost of such a telescope would rival the national debt." Obviously, Gossamer telescopes will have to break the cost paradigm alongside with its technology paradigm.

Technology Emphasis

The large aperture part of the Gossamer Initiative will conduct technology development to define advanced concepts for very large gossamer apertures (> 20 meters), identify key technologies, and begin development of these technologies in a program culminating in proof-of-concept hardware demonstrations ($\geq$ 1 meter diameter).
The Gossamer Initiative will only develop ground technology demonstration and will rely on other opportunities and programs, such as the New Millennium Program, to advance the technology to space flight validation levels.

The planned activities will include development and demonstration of concepts for telescopes, antennas, or other large apertures. Areas of specific interest are:

- Concepts to enable very large, ultra-lightweight (areal density < 1 kg/m^2) optical systems for astronomical telescopes and Earth imagers observing in the sub-millimeter/Far IR, IR, Visible, UV, and X-ray spectral regions.

- Concepts to enable large deployable and/or inflatable antennas for use in space-based radio astronomy, microwave radiometry, radar, and communications.

Desirable performance characteristics for these systems and in particular for near term proof-of-concept technology and hardware development are:
- High packaging efficiency for small launch volume
- Rapid, low-cost manufacturing
- Design traceable to space-qualified materials
- Robust system response to re-pointing of aperture
- High surface reflectivity after repeated deployment

Near term development of proof-of-concept hardware will be strongly encouraged. The visionary program goal is an areal density of ≤ 1.0 kg/ m^2. However, it is expected that initial proof-of-concept hardware will exhibit areal density >1 kg/m^2 . Such hardware will be developed if it offers a significant potential advantage in performance and rapid, low-cost manufacturing and if, in particular, it represents an intermediate step traceable to designs meeting the $\leq$1kg/m^2 goal. Such hardware for diffraction-limited optical performance at visible and IR wavelengths should strive for an immediate areal density goal of <5kg/m^2.

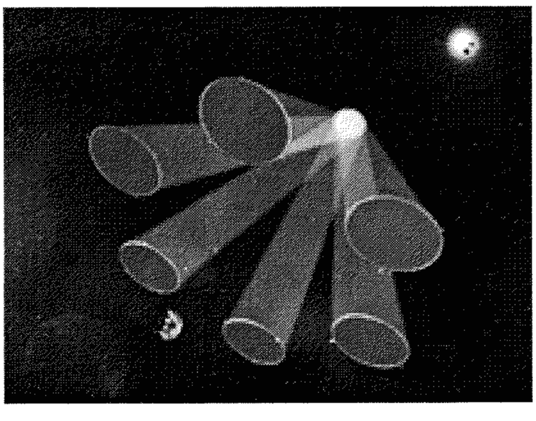

Figure 3 Gossamer telescope concept by Roger Angel, University of Arizona

In the solar sail area the main objective is to rapidly advance the readiness of key technologies so that a solar sail space flight experiment could be conducted within the next 5-10 years.

Listed below are the types of developments that will be conducted under the Gossamer Initiative.

Concepts and System Studies:
- Innovative designs for solar sails, with emphasis on packageability, areal density, structural stability, deployability, controllability, and scalability to large sails (> 100 m). Concepts for 3-axis stabilized sails, spin-stabilized sails, sails without support booms, and sails that function as antennas or other instruments will also be included.
- Innovative concepts for sail stowage and deployment, including low-volume packaging, launch restraints, deployment methods, and control of deployment dynamics.
- Innovative concepts for using the sails not only as a propulsion system but also to combine other spacecraft functions such as for communications, science gathering, power generation and other.

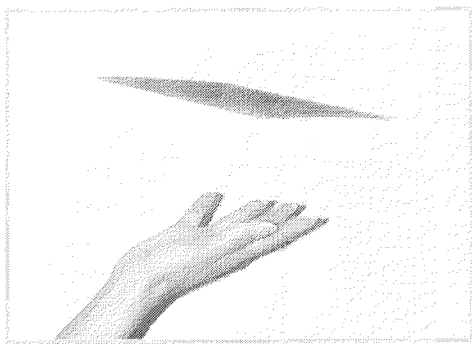

Figure 4 Innovative carbon microtruss fabric developed by the Energy Science Labs, Inc.

Materials and Fabrication:
- Ultra-lightweight (< 2 g/m^2), high-strength, reflective sail materials with inherent tear resistance. Materials will have operational lifetimes greater than 10 years, and will be resistant to ultraviolet radiation, particle radiation, and extreme temperatures.
- Advanced sail material concepts such as microporous membranes, microtruss fabrics, biomimetic materials, and materials that sublime when exposed to space.
- Low-cost techniques for fabrication, coating, seaming, and handling of large-area membranes. The research will involve fabricating large-scale films to validate proposed manufacturing and assembly processes and verifying scalability of mechanical, thermal and optical properties.

- Advanced methods for sail thrust vector control without mechanisms, such as smart materials for sail warping, and variable reflectivity materials.
- Candidate material testing to assess the applicability for sail missions. This will include measuring critical properties such as strength, modulus, areal density, reflectivity, thermal tolerance, emissivity, blocking tendency, toughness and radiation sensitivity.

It is expected that both large apertures and solar sails will rely heavily on multifunctional and adaptive systems. The development of multifunctional and adaptive systems applicable to large, ultra-lightweight deployable or inflatable structures will be an important part of the program. To achieve breakthroughs in lowering the cost, launch volume, and mass of future missions it will be necessary to develop highly integrated multifunctional membranes with embedded thin-film electronics, sensors, actuators, and power sources.

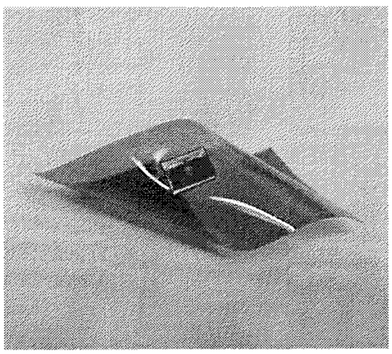

Figure 4 Thin electronics on a Kapton substrate developed by University of Arkansas

Technologies of specific interest for Gossamer Initiative will be:

- Advanced materials and processes for integrating membranes, electronics, sensors, actuators, power sources, and their associated interconnects into a unified and adaptable structure. Methodology and modeling techniques needed to optimize materials and process selection for integrating MEMS devices with CMOS electronics.
- Lightweight, distributed power systems, and active or passive thermal control systems integrated with membrane structures. Models will be needed which optimize power storage and thermal management designs.
- Materials with controllable surface properties that, when combined with integral control electronics, could adapt to changing environmental conditions or mission needs (e.g., changing optical properties to steer a solar sail).
- Concepts and components for active, adaptive wavefront control systems, including shape control of membrane mirrors, with correction to < 1 wavelength.
- Adaptive systems for measuring and correcting surface figure and wavefront errors and for controlling structural geometry and dynamics.
- Thinning processes for substrates and bonding processes for attachment to thin films and membranes.

Revolutionary gossamer system concepts, and evaluation of their potential performance in support of Earth Science, Space Science, and Human Exploration and Development of Space (HEDS) missions will be conducted. These novel concepts will provide either an order of magnitude improvement over existing concepts, or enable missions that were previously considered impossible, while keeping cost and risk within reasonable limits. System concepts will include gossamer elements such as deployable or inflatable structures, multifunctional membranes, tethers, or completely new gossamer technologies. An example concept is a gossamer spacecraft capable of modifying its shape or other functional characteristics so that it can adapt to different mission phases, such as atmospheric entry, descent, landing, and surface exploration.

Customer Relevance

Solar sails and large ultra-light apertures have crosscutting benefits to many NASA enterprises. Sails are beneficial to many Sun Earth Connection (SEC) roadmap missions including Solar Polar Imager and Space Weather Sentinels. Several Solar System Exploration (SSE) roadmap missions such as Neptune and Europa Orbiters or Titan Explorer can also benefit from sails.

Sails can be also used in the future as occulters for Astronomical Search for Origins (ASO) and Structure and Evolution of the Universe (SEU) missions and as orbit raising propulsion for Earth Science. Special type of sails can function as sunshields for cold telescopes for Earth and Space Science. Sails can also deliver cargo for human exploration of Mars.

Large apertures are also crosscutting in their applications. They are needed for radiometers, radars and event monitors for Earth Science. The Origins theme is interested in submillimeter and near IR telescopes. The SEU theme has requirements for RF Very Long Baseline Interferometry (VLBI) telescopes and "non-coherent imagers." Deep space antennas, solar concentrators and optical communication systems will be needed for SSE and SEC; and high bandwidth communication systems for Human Exploration Development of Space (HEDS).

Technology developed by the Gossamer Initiative has crosscutting products that span Earth Science, Space Science and HEDS. No single task in the program is aimed at just one particular mission. For a more in depth treatment of the enterprises, themes and missions benefiting from Gossamer the reader is directed to the program customers' presentations given at the Gossamer Workshop in October 1999. All presentations can be found at http://gossamer.jpl.nasa.gov/workshop/index.html

Conclusion

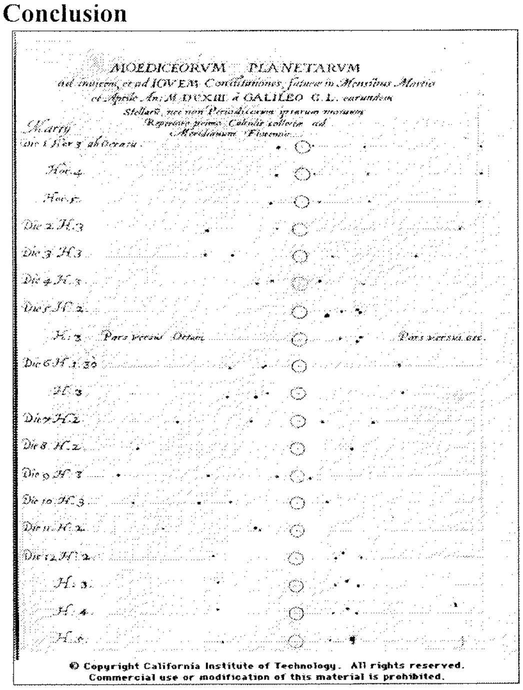

Figure 5 Galileo Galilei's original sketches of the moons of Jupiter

In 1609 Galileo Galilei pointed his 3 cm diameter telescope at Jupiter. He was astounded to find a few tiny dots positioned in a straight line across the planet's diameter. When Galileo looked the next day there were more dots and their order has changed. Figure 5 shows the original page from Galileo's "Sidereal Messenger" which reported this discovery. The dot that is the closest to Jupiter is of course its famous moon Io. Figure 6 shows the view of the same moon Io obtained almost 400 years later by the HST. We are hopeful that within the next few years we will have an image of an extrasolar planet that is as good as Galileo's first sketch of Io – a dot. The Gossamer telescope will turn that dot into an image equivalent to the HST's resolution of Io.

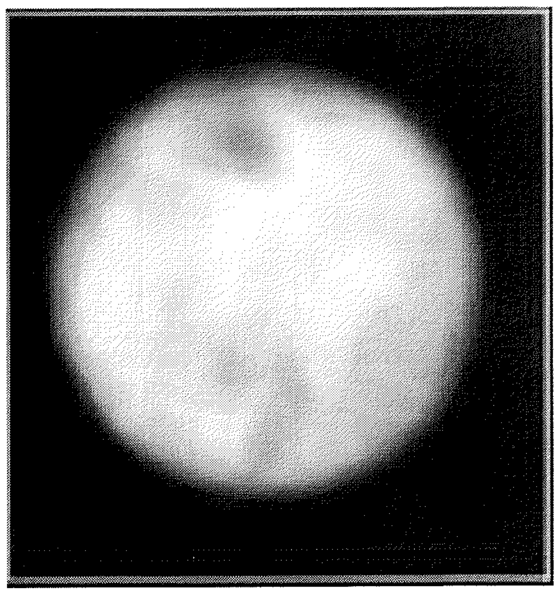

Figure 6 HST's view of Io

A solar sail fly-by of an extrasolar planet system would produce an image comparable to the view of Io revealed to the Galileo spacecraft as shown on figure 7. To accomplish these astounding imaging feats five orders of magnitude improvement over the state of the art is needed in structures and apertures. The Gossamer Initiative technology development will assure that the human race we will not have to wait another 400 years for these breakthroughs.

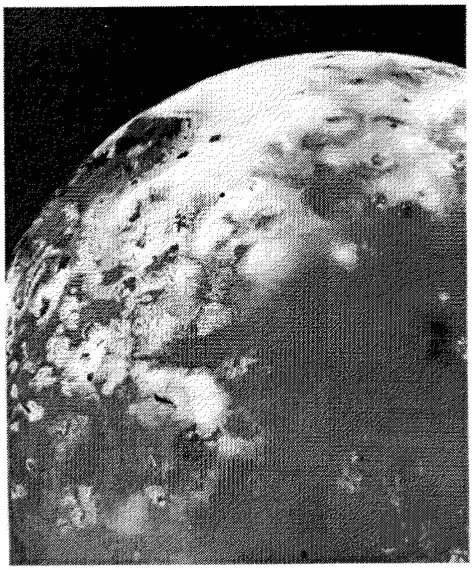

Figure 7 Picture of Io taken by the Galileo spacecraft